10/520109
DT12 Rec'd PCT/PTO 03 JAN 2005

APPARATUS AND METHOD FOR CLEANING EXHAUST GAS FROM AN INTERNAL COMBUSTION ENGINE

[0001] Specification

[0002] The present invention relates to an apparatus for cleaning exhaust gas from an internal combustion engine and to a method for operating such an apparatus. The apparatus has an exhaust gas line, leading away from the engine, and an ozone source for enriching the exhaust gas stream with ozone. The invention also relates to a method for regenerating a particle filter in an apparatus for cleaning exhaust gas. The invention pertains preferably to Diesel engines that are disposed in particular in motor vehicles.

[0003] Prior Art

[0004] From European Patent Disclosure EP 1 026 373 A2, an apparatus for cleaning the exhaust gas stream of an internal combustion engine is known, having an ozone source which serves to enrich the exhaust gas stream with ozone. According to this reference, an oxidizing catalytic converter and downstream of the oxidizing catalytic converter a particle filter are disposed in the exhaust gas line. The delivery of ozone serves to clean the particle filter of particles that have deposited there during engine operation. The enrichment of the exhaust gas stream with ozone is effected between the oxidizing catalytic converter and the particle filter. The ozone then reaches the particle filter along with the exhaust gas. The particles react with the delivered ozone, since ozone has very low reactivity, and self-ignition of the particles takes place even at relatively low temperatures of the exhaust gas stream. The particles oxidize and are thus eliminated, as a result of which the particle filter is cleaned.

[0005] From German Patent Disclosure DE 38 34 920 A1, a method and an apparatus for eliminating soot deposited in an exhaust gas filter of an internal combustion engine is also

known; discharge currents are generated that on the one hand heat up the soot particles and on the other generate ozone, which oxidizes the soot particles and thus reinforces the burnoff of soot from the filter.

[0006] The invention is intended to improve the operation of an exhaust gas cleaning system in terms of energy consumption. According to the invention, this can be accomplished on the one hand by providing that the energy required for regenerating a particle filter is reduced, and on the other by reducing the consumption of the engine itself. Pollutant emissions from an internal combustion engine are also to be improved.

[0007] Advantages of the Invention

[0008] The apparatus of the invention for cleaning exhaust gases from an internal combustion engine has an exhaust gas line, leading away from the engine, and an ozone source for enriching the exhaust gas with ozone; the ozone source is embodied such that it generates a continuous ozone-containing gas stream, so that particles flowing in the exhaust gas line are virtually completely oxidized (combusted). This makes it possible to dispense with a particle filter entirely.

[0009] Because the particles that occur in engine operation are continuously oxidized with ozone, it becomes possible to dispense with a particle filter in the exhaust gas line, without losses of quality in cleaning the exhaust gas. This reduces the flow resistance in the exhaust gas line and thus the exhaust gas counterpressure and as a result the energy consumption of the engine. The high surface area of the particles, which are very predominantly soot with a primary particle size of less than 100 nm, facilitates oxidation during the dwell time in the exhaust gas train, that is, the time-of-flight of the gases.

[0010] The ozone is a strong oxidant for the particles in the exhaust gas stream. Because of the presence of the ozone, the oxidation of the particles begins at low temperatures in the exhaust gas line, which may even be below 150°C. The oxidation of the particles is an exothermic reaction, which takes place when the atmosphere has suitable reaction conditions - that is, the presence of oxygen in sufficient concentration - and a high enough temperature. The ozone is a metastable oxygen compound, which breaks down after a short time, giving up energy. In the process, unbonded, highly reactive oxygen atoms (radicals) are released, which increase the reactivity of the atmosphere, and as a result the ignition temperature for combusting the particles drops considerably.

[0011] Because of the metastability of the ozone, it cannot be stored; it must be made as needed and at least in the vicinity of the exhaust gas stream to be cleaned. An ozone source must therefore be provided, in which ozone is generated. Ozone can be recovered from an oxygen-containing atmosphere by supplying energy suitable for splitting oxygen molecules. This can be done for instance by means of electromagnetic alternating fields or uv light. Electrochemical ozone generation is possible, with water as an educt. Enriching the exhaust gas stream with ozone can, in advantageous features of the invention, be done on the one hand by ozone generation in the exhaust gas stream itself, or by ozone generation in an ozone source disposed outside the exhaust gas line. In ozone generation in the exhaust gas stream itself, however, a sufficient quantity of oxygen must be present in the exhaust gas stream itself. This is attainable in the event of lean combustion of the fuel in the engine, or by admixing air into the exhaust gas stream. In the case of external generation of the ozone, this can be done in a reaction chamber through which aspirated ambient air flows.

[0012] In a method of the invention for cleaning an exhaust gas stream, which can be employed in particular in an apparatus of the invention for cleaning exhaust gas, a continuous enrichment of the exhaust gas stream with ozone is effected, such that oxidation with

complete combustion of the particles in the exhaust gas stream already takes place during the flow through the exhaust gas line, making a particle filter unnecessary.

[0013] The metering of the ozone is preferably effected such that the temperature of the exhaust gas stream in the enrichment with ozone generated by the ozone source is above the self-ignition temperature of the (soot) particles. The metering of the ozone can be done such that a particle sensor, which measures the remaining particle content in the exhaust gas stream, is provided in the exhaust gas line, spaced apart downstream from the point of enrichment with ozone. This measurement can also be done indirectly, for instance by way of detecting the exhaust gas temperature in this region of the exhaust gas line. The enrichment with ozone is effected such that the particle content at the particle sensor is below a predetermined limit value. For instance, the predetermined limit value is determined such that it either meets or is below legally specified exhaust gas limit values for particles - that is, soot. In addition or alternatively, it may be provided that the temperature of the exhaust gas stream be detected upstream of the point of enrichment with ozone. The temperature increase between the temperature sensor upstream of the enrichment with ozone and a temperature sensor downstream of the enrichment with ozone is a measure for the energy that is liberated in the combustion of the particles. If this temperature difference is maximized, at the least possible enrichment with ozone (ozone content), then this can be assessed as showing that a maximum degree of combustion of the particles has been reached.

[0014] In another aspect of the invention, in an exhaust gas cleaning system that has a particle filter disposed in the exhaust gas line, ozone can be introduced upstream of this particle filter, after the engine is shut off.

[0015] Introducing the ozone brings about regeneration of the particle filter. Introducing the ozone, possibly in conjunction with a carrier gas, can be done for instance by means of a blower. The advantage of performing a regeneration of a particle filter with the engine

switched off is that the ozone concentration can be kept very high inside the particle filter with little expenditure of energy, since no dilution with the exhaust gas from the engine occurs. Moreover, without an additional exhaust gas stream, the exothermic oxidation of the particles causes a marked increase in the filter temperature, since the convective heat dissipation is reduced substantially because of the lesser flow rate. Both effects lead to a markedly reduced regeneration time and a lesser expenditure of energy. If only such a regeneration of the particle filter is contemplated, or in other words if periodic regeneration is not done during driving, then the ozone generator can be made smaller and hence can be realized less expensively.

[0016] The introduction of the ozone is preferably done at a residual temperature of the particle filter that enables a self-ignition of the particles at an attainable ozone concentration. Preferably, the burnoff of the particles in the particle filter can be monitored by means of a temperature sensor. Then it is possible in particular to control the delivery of ozone such that the temperature of the particle filter is above a minimum temperature by a certain amount; the minimum temperature may for instance be approximately 150°C. If there is a decrease in trend to the temperature of the particle filter, then the ozone delivery is increased, to promote the combustion that occurs; if the temperature has risen too far, the ozone delivery is reduced, to prevent damage to the particle filter. In this way, uniform burnoff of the particles can be achieved.

[0017] A further aspect of the invention provides that immediately before the start of the engine, the exhaust gas line is rinsed with a gas stream enriched with ozone.

[0018] It is known that a certain quantity of hydrocarbon can deposit on the inner surfaces of the exhaust gas line in the exhaust gas train after the engine is switched off. These hydrocarbons can escape when the engine is started, because the oxidizing catalytic converter is still cold and hence is ineffective. These starting emissions can be avoided if the exhaust

gas train is rinsed with an ozone-containing gas stream before the starting process, for instance during the preglow phase of a Diesel engine. Because of the presence of the ozone, a combustion of the hydrocarbons that not only eliminates the hydrocarbons but also rapidly increases the temperature in the exhaust gas line occurs.

[0019] In particular, it can be provided that the gas stream enriched with ozone be introduced upstream of an oxidizing catalytic converter. This promotes the reaching of the operating temperature of the oxidizing catalytic converter after cold starting. Moreover, with simultaneous rich combustion in the engine, the exhaust gas stream can initially carry along further uncombusted hydrocarbons, which are combusted exothermically because of the presence of the ozone. This provision as well promotes a rapid attainment of the operating temperature of the oxidizing catalytic converter. Adjusting the fuel injection into the combustion chambers of the engine to "late" is equally advantageous for this purpose. With an increasing temperature in the exhaust gas train, the delivery of a gas stream enriched with ozone, or in other words the ozone concentration, can be reduced.

[0020] Drawing

[0021] Exemplary embodiments of the invention are shown in the drawing and will be described in further detail below; shown are:

[0022] Fig. 1: in a schematic illustration, an apparatus of the invention for cleaning exhaust gas, with an ozone source disposed outside the exhaust gas line;

[0023] Fig. 2: in a schematic illustration, an apparatus of the invention for cleaning exhaust gas, with an ozone source disposed inside the exhaust gas line;

[0024] Fig. 3: in a schematic illustration, an exhaust gas cleaning system with a particle filter;

[0025] Fig. 4: the flow chart of a method for controlling the ozone concentration, with continuous enrichment with ozone;

[0026] Fig. 5: the flow chart of a method for generating a particle filter after the engine is switched off; and

[0027] Fig. 6: the flow chart of a method for rinsing the exhaust gas line with ozone-enriched gas before the vehicle is started.

[0028] Fig. 1 schematically shows one embodiment of an apparatus of the invention for cleaning exhaust gas, with an ozone source disposed outside the exhaust gas line 7.

[0029] The exhaust gas line 7 leads from the engine 1 to the tailpipe 13 of the exhaust gas line 7, where the exhaust gases leave the exhaust gas line 7. In the exhaust gas line 7 and associated with the exhaust gas line 7, there are various elements for cleaning exhaust gas,. which together form an exhaust gas cleaning system. The exhaust gas cleaning has the purpose of cleaning the exhaust gases expelled from the engine 1 of entrained pollutants to the maximal extent, or at least enough to meet legal requirements. The pollutants also include particles, for the most part soot, which occur because of incomplete combustion in the engine. The soot or particle formation is especially pronounced in Diesel engines. Such particles have a particle size of less than 100 nanometers (100 nm). Besides the elements shown in the drawing, still other elements for exhaust gas conditioning may be provided at a suitable point.

[0030] In terms of the flow direction of the exhaust gases in the exhaust gas line 7, there is first an oxidizing catalytic converter, inside which oxidation reactions, which have for instance been incomplete, of hydrocarbons and NO_x to form CO_2 and NO_2 in the presence of a catalyst take place. Particles flow through such an oxidizing catalytic converter without being oxidized.

[0031] In the further course of the exhaust gas line, there is a temperature sensor, which via the signal line 10 detects the exhaust gas temperature at that point and sends it to the control unit 6. Downstream of the temperature sensor, the supply line 9 discharges into the exhaust gas line. Via the supply line 9, an ozone-containing gas stream is introduced into the exhaust gas stream, which as a result is enriched with ozone. As a result of the enrichment with ozone, a combustion of the particles is effected, substantially during the course of traveling the flight distance to the final muffler 4. The combustion starts because of the temperature in the exhaust gas line and the ozone concentration by self-ignition. The energy released during the combustion heats the exhaust gases, and the exhaust gas temperature is detected again downstream of the reaction path before it enters the final muffler 4 and is delivered to the ozone source 5 via a signal line 11 of the controller 6.

[0032] After the exhaust gases have flowed through the final muffler 4 and the tailpipe 13 of the exhaust gas line, they leave the exhaust gas system. They are cleaned, and even if no particle filter were disposed in the exhaust gas system, they are sufficiently free of particles.

[0033] Via the supply line 9, the continuous delivery of an ozone-enriched gas stream is effected. The ozone generation, or the enrichment of an educt with ozone, is effected by means of the ozone generator 5. An educt, such as air, is supplied to this ozone generator 5 via the intake line 15. In the reaction chamber 16, ozone is generated in the educt, and as a result the product, which is an ozone-enriched gas, is created. A continuous stream of product gas reaches the exhaust gas line.

[0034] The ozone generation of the ozone source is controlled by the control unit 6, for instance by a method shown in Fig. 4. Various reaction chambers 16 or forms of ozone generation are conceivable. The ozone generation can be done in a known manner by plasma generation, UV irradiation, or electrochemically. Typically, the ozone-containing gas stream thus generated has an ozone concentration of 10 to 30%. As the educt, oxygen, oxygen from the air, or water (electrochemical methods) may be used. The metering of the ozone-containing gas stream, or the metering of the ozone generation, can be regulated by regulating the educt stream, the generator capacity, or the product stream (ozone-containing gas stream in the supply line 9). The regulation by the control unit can be done in particular as a function of performance graph data of the engine, temperature sensors, and particle sensors. It is thus possible, if an unfavorable operating state leading to high particle formation is established, to increase the ozone enrichment in the exhaust gas stream at the same time.

[0035] The embodiment of Fig. 2 differs from the embodiment of Fig. 1 in terms of the disposition of the ozone generator. The ozone source 5 is disposed in the region of the exhaust gas line 7, and its reaction chamber is located inside the exhaust gas line 7 itself. The ozone is formed essentially from oxygen contained in the exhaust gas stream. Oxygen is contained in the exhaust gas stream whenever the engine 1 is operated with a lean mixture preparation. Alternatively or in addition, a bypass line 14 may also be provided, which introduces air from the intake tract of the engine into the exhaust gas line 7, bypassing the combustion chambers. The introduction of the air can be done already upstream of an oxidizing catalytic converter 2 that is disposed upstream of the ozone source 5.

[0036] As an alternative embodiment to that of Fig. 1, in Fig. 2 the temperature sensor upstream of the ozone source is omitted, since instead of a further temperature sensor upstream of the final muffler 4, a particle sensor is disposed, which detects the particle content of the exhaust gas stream and sends its measurement values over the signal line 11 to the control unit 6, which in turn, via the control line 11, varies the operation of the ozone

source 5 such that the particle content at the particle sensor does not exceed a predetermined value.

[0037] The ozone generation itself, and its regulation via the control unit 6, can also be done in the ways described in conjunction with Figs. 1 and 6.

[0038] Fig. 3 schematically shows an exhaust gas cleaning system of the invention, with an ozone source 5 disposed outside the exhaust gas line 7; a particle filter 3 is disposed in the exhaust gas line 7.

[0039] The exhaust gas line 7 leads from the engine 1 to the tailpipe 13 of the exhaust gas line 7, where the exhaust gases leave the exhaust gas line 7. In the exhaust gas line 7 and associated with the exhaust gas line 7, there are various elements for cleaning exhaust gas, which together form an exhaust gas cleaning system. The exhaust gas cleaning has the purpose of cleaning the exhaust gases expelled from the engine 1 of entrained pollutants to the maximal extent, or at least enough to meet legal requirements. The pollutants also include particles, for the most part soot, which occur because of incomplete combustion in the engine. The soot or particle formation is especially pronounced in Diesel engines. Such particles have a particle size of less than 100 nanometers (100 nm).

[0040] In terms of the flow direction of the exhaust gases in the exhaust gas line 7, there is first an oxidizing catalytic converter, inside which oxidation reactions, which have for instance been incomplete, of hydrocarbons and NO_x to form CO_2 and NO_2 in the presence of a catalyst take place. Soot particles flow through such an oxidizing catalytic converter, at the relevant temperatures, for instance of < 280°C, without being oxidized.

[0041] Both upstream and downstream of the oxidizing catalytic converter, a supply line 8 and 9, respectively, is disposed for intermittently supplying ozone-containing gas to the

exhaust gas line 7. Downstream of the supply line 9, there is a particle filter 3, through which the exhaust gas flows. Particles contained in the exhaust gas stream are trapped by the particle filter. The exhaust gas temperature can be detected at or downstream of the particle filter and sent to the controller 6 of the ozone source 5 over a signal line 11. After flowing through the final muffler 4 and the tailpipe 13 of the exhaust gas line, the exhaust gases leave the exhaust gas system.

[0042] So that the particle filter 3 will not become clogged by the particles that have precipitated out, it must be regenerated again and again by combustion of the precipitated particles. Via the supply line 9, an ozone-containing gas stream can be introduced into the exhaust gas line 7, as a result of which a regeneration is effected of the particle filter 3 disposed downstream in the exhaust gas line 7. Because of the enrichment with ozone, combustion of the particles trapped in the particle filter 3 is effected, so that the filter is freed of the deposits formed, or in other words regenerated. A method for regenerating a particle filter is shown in Fig. 5; according to the invention, the regeneration is effected immediately after the engine 1 is switched off, or in other words at a time when no further exhaust gas stream is present. This makes it possible to equip the system with an ozone source of relatively low capacity, without impairing its function.

[0043] The combustion in the particle filter starts by self- ignition, because of the temperature in the exhaust gas line 7 and the ozone concentration generated. The energy released during the combustion heats the gases of combustion, and as a result the temperature in the particle filter increases. The temperature required for the self-ignition is maintained in the process.

[0044] The delivery of an ozone-enriched gas stream is effected via the supply line 9, and the flow of the gas stream can be generated via the blower 17, which is part of the ozone generator 5. The ozone generation or the enrichment of a starting gas with ozone is done via

the ozone generator 5. Via the intake line 15, educt, such as air, is supplied to this ozone generator. In the educt, ozone is generated in the reaction chamber 16, and as a result the product, which is an ozone-enriched gas, is produced. A stream of product gas reaches the exhaust gas line. The ozone generation of the ozone source is controlled by the control unit 6, for instance by a method illustrated in Fig. 5. Various reaction chambers 16 and forms of ozone generation are conceivable. The generation of the ozone can be done in a known manner by plasma generation, UV irradiation, or electrochemically. Typically, the ozone-containing gas stream thus generated has an ozone concentration of 1 to 20%. Oxygen, oxygen from the air, or water (electrochemical methods) can be used as the educt. The metering of the ozone-containing gas stream and the metering of the ozone generation can be regulated by regulating the educt stream, the generator capacity, or the product stream (ozone-containing gas stream in the supply line 9).

[0045] It is furthermore possible according to the invention, via the supply line 8, to rinse the exhaust gas line 7 with ozone-containing gas, before the engine is started. To that end, ozone-containing gas is generated by the gas source 5 and carried into the exhaust gas line 7 through the supply line 8. The gas flows through the oxidizing catalytic converter 2 to the tailpipe 13. No later than whenever, after the start, additionally warm exhaust gases flow from the engine in the exhaust gas line, hydrocarbons that have been deposited in the exhaust gas line 7 are combusted because of the presence of the ozone. No later than shortly after engine starting, the generation of ozone-containing gas can be ended. A corresponding method, in which rapid heating of the catalytic converter 2 can be done simultaneously via the delivered ozone, is described in Fig. 6.

[0046] A supply line 8 for rinsing the exhaust gas train can also be provided in the same way in the embodiment of Fig. 1, and correspondingly a method in accordance with Fig. 6 can then be performed.

[0047] Fig. 4 shows a method for performing an exhaust gas cleaning with continuous enrichment of ozone in the exhaust gas stream, in the way it is performed if the exhaust gas line 7 is free of a particle filter. In step 401, the question is asked whether the engine is in operation, since this the prerequisite for the present method. As long as that is not the case, no further method steps are performed. As soon as it is ascertained in step 401 that the engine is in operation, then in step 402 the exhaust gas stream is enriched with ozone in the previously effected quantity or concentration; it does not matter whether the ozone is generated in the exhaust gas line itself or in an external ozone source and delivered via a supply line 9.

[0048] In step 403, the question is then asked whether the exhaust gas temperature downstream of the enrichment with ozone is higher than upstream thereof. This is true whenever self-ignition has occurred and, over the flight distance of the exhaust gases after the ozone concentration has been generated and until the downstream temperature sensor is reached, a combustion of particles has taken place. If that is not the case, then a jump is made to step 405, and the ozone concentration to be generated is increased; the increase can be done by an increment of predetermined size, such as 0.5%. Via the control unit 6, the ozone source 5 is triggered in accordance with the generation of the higher ozone concentration.

[0049] In step 404, the question is asked whether the temperature at the downstream measurement point is maximal, or in other words if it increases further upon a further increase in the ozone concentration. To that end, the temperature is compared with the temperature measured there in the previous inquiry. If the current temperature is greater than the previous one, and if an increase in the ozone concentration has accordingly occurred, then the combustion of particles can be increased by increasing the ozone concentration. A jump is then made to step 405, and the ozone concentration is increased by a further increment. A jump is also made to step 405 if the current temperature is lower than the previous one and a reduction in the ozone concentration in accordance with step 406 has accordingly occurred.

[0050] Otherwise, the most recent increase or most recent decrease in the ozone concentration in the exhaust gas line has not led to an increased or reduced combustion of particles, respectively; the combustion until now was and continues to be complete. With a view to reducing the energy consumption for generating the ozone, the ozone concentration is therefore reduced by one increment in step 406.

[0051] Fig. 5 shows a method for regenerating a particle filter 3 which is performed after the engine is shut off. A corresponding exhaust gas cleaning system having a particle filter 3 is shown in Fig. 3 and described in conjunction with it. In step 501, the question is asked whether the engine has been shut off. If not, a return is made to step 501. As soon it is found in step 501 that the engine has been shut off, then in step 502 the question is asked whether the temperature of the particle filter has dropped to a desired amount, which is above the self-ignition temperature of the deposited particles at an attainable ozone concentration. As soon as that has happened, then in step 503, ozone is introduced into the particle filter.

[0052] Next, in step 504, the question is asked whether the temperature is above an intended limit value. If so, then a return is made to step 507, and the ozone concentration to be introduced is reduced by a predetermined increment, such as 0.5%, and a jump is then made to step 503.

[0053] Otherwise, in step 505, the ozone concentration to be generated is increased by one increment. After that, in step 506, the question is asked via a sensor whether the deposited particles have been combusted completely. This can be accomplished for instance from the course of the temperature curve as a function of the ozone concentration, or by means of a differential pressure sensor, which detects the pressure difference via the particle sensor. If the combustion of the deposited particles has not yet been done completely, a jump is made to step 503. If not, the ozone generation and the introduction of ozone-containing gas into the particle filter is ended. The method is terminated.

[0054] Fig. 6 shows the schematic illustration of a method for rinsing the exhaust gas line and an oxidizing catalytic converter with ozone-containing gas before an internal combustion engine is started. In step 601, the question is asked whether the engine is to be started. For a Diesel engine, for instance, this is done by asking whether a preglow operation has been initiated. If so, then in step 602 the exhaust gas line is rinsed by delivering an ozone-containing gas stream, for instance through a supply line 8, which discharges upstream of the oxidizing catalytic converter 2 - shown in Fig. 3, but this can be realized in the same way in an embodiment without a particle filter as in Fig. 1. The rinsing can in particular be done for a predetermined length of time. To keep the predetermined length of time as short as possible, as high as possible a volumetric flow of high ozone concentration must be briefly generated by the ozone generator. During the rinsing operation, starting of the engine can therefore be blocked; in that case, engine starting is not enabled until the conclusion of the rinsing operation. A transition is then made to step 603. In step 603, ozone-containing gas continues to be introduced into the exhaust gas line 7 by the supply line 8 upstream of the oxidizing catalytic converter 2; the engine combustion is controlled such that the exhaust gases still contain combustible hydrocarbons. This can be effected by means of a very late fuel injection or by means of a rich mixture preparation in the engine. Both the ozone delivery (concentration, volumetric flow) and the content of hydrocarbons can be done degressively with increasing temperature in the oxidizing catalytic converter 2. In step 604, the question is asked whether the oxidizing catalytic converter has reached its operating temperature. If not, a jump is made to step 603. Otherwise, the introduction of ozone-containing gas into the exhaust gas line 7 upstream of the oxidizing catalytic converter 2 and the method are both terminated.